Environmental Management System and Lifecycle Carbon Accounting for Road Pavement Works Programme

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Introduction

Transport Infrastructure Ireland (TII) has embedded an Environmental Management System (EMS) into its pavement management programme to enable lifecycle carbon accounting and support national climate goals.

Through the Deighton Total Infrastructure Management System (dTIMS), TII quantifies Global Warming Potential (GWP) for individual pavement segments across the national road network. The system captures emissions from vehicle operations (influenced by pavement condition and speed), construction activities, material use, and maintenance-related delays.

By comparing "do-nothing" and programmed treatment scenarios, TII identifies opportunities to reduce carbon emissions while maintaining performance and cost efficiency.

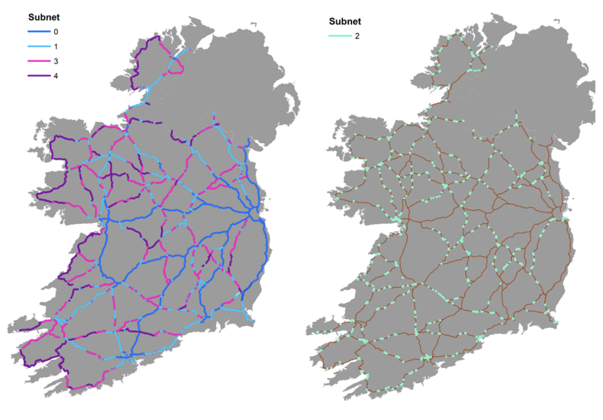
The Irish National Road Network





The Irish national road network is very diverse in terms of pavement design, structural capacity, drainage, geometric alignment. To better manage the overall network TII have broken the Overall Network into 5 Subnetworks. Subnetworks display internally consistent characteristics and behaviour.

Subnet		Classification	Length (km)	% Of Network
0	Motorway + Dual Carriageways	High speed, high volumes pavement, made up of Motorway and Dual Carriageway sections of the network.	1200	23%
1	Engineered Single Carriageway	Typically carry reasonably large volumes of traffic and are identified by the presence of hard shoulders adjacent to the carriageway.	1200	22%
2	Urban Roads	Low to medium speed, typically short sections through towns that are not bypassed, also includes longer sections within the cities and larger towns where National Roads start and end.	700	13%
3	Legacy Pavement - High Traffic	Legacy subnetwork, typically constructed without formal geometric or pavement design. Typically carries traffic volumes less than 10,000 AADT.	1300	24%
4	Legacy Pavement - Low Traffic	Legacy subnetwork, typically constructed without formal geometric or pavement design. Typically carries traffic volumes less than 5000 AADT.	950	18%

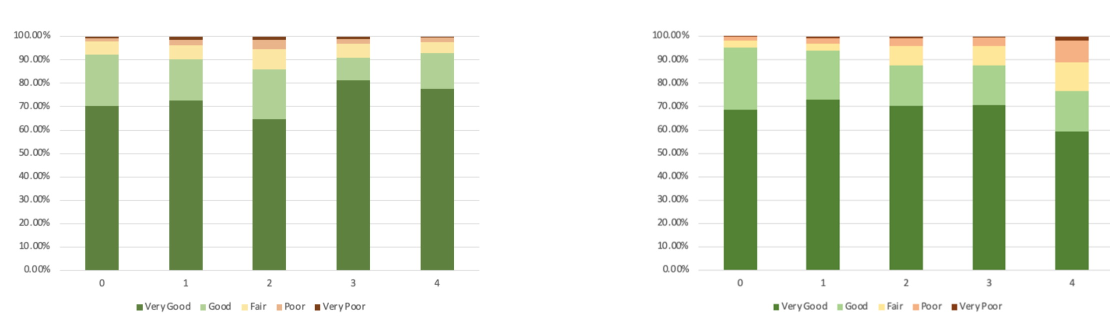


Managing The Network

Pavement condition is measured annually by TII across the network. Key Performance Indicators (KPI's) are employed to monitor and manage the Network include e.g.:

- International Roughness Index (IRI)
- RUT Depth (RUT)
- Longitudinal Evenness (LPV)

Qualitative Descriptors are employed: Very Good, Good, Fair, Poor, Very Poor. Different Subnets have different definitions of Very Good, Good etc. TII;s Target is 95% in Fair or Better for all parameters on all Subnets



Current Network Condition

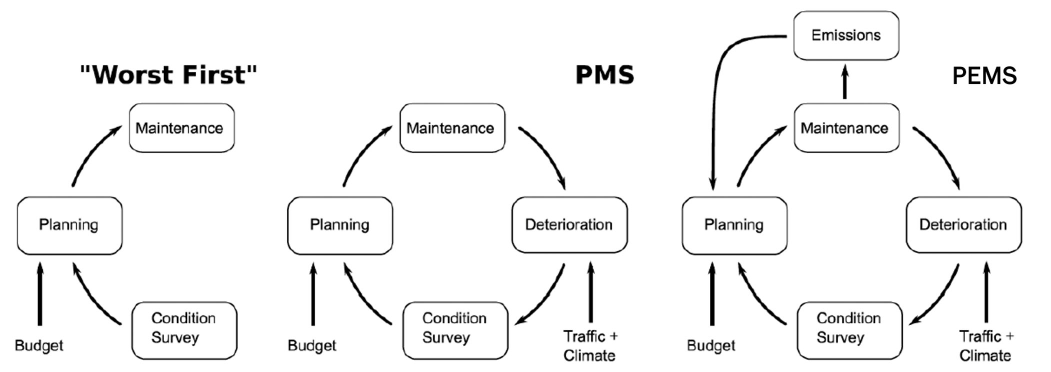
Traditionally, Pavement Management Systems (PMSs) have been used to achieve these targets by generating programmes which optimise the network based on cost and performance. The optimisation process selects the solutions which gives the highest level of performance for a given expenditure constraint.

The EMS implemented by TII has extended the system beyond purely performance and cost domains to incorporate environmental considerations, primarily GWP associated with pavement maintenance, into the optimisation framework.

Pavement Environmental Management Systems

PEMS are essential for advancing sustainable infrastructure practices. They integrate environmental considerations across all stages of pavement project delivery spanning planning, design, construction, maintenance, and end-of-life processes. PEMS constituents Include e.g.:

- Environmental Impact Assessment (EIA)
- Life Cycle Analysis (LCA)
- Material Selection and Recycling
- Energy Consumption and Efficiency
- Water Management
- Air Quality and Emission Control
- Monitoring and Reporting



Evolution of PMS to PEMS (Adapted from Gosse et al., 2013)

TII PEMS GWP Sources & Savings

The TII PEMS looks at 3 sources of Carbon/GWP:

(i) User GWP (user vehicle emissions adjusted for pavement condition)
(ii) Embedded GWP generated by pavement maintenance works (material production, transport & placement)
(iii) Delay GWP due to maintenance activities (vehicles idling at roadworks, detours etc)

The short-term increase in Embedded and Delay GWP generated by pavement maintenance activities is offset by long-term reductions in User GWP accruing from driving on improved pavement.

Backlog GWP is also considered. Backlog is defined as the portion of the network that remains in Poor or Very Poor condition at the end of the analysis period. Backlog GWP is the notional GWP for the works that would be required to restore this portion of the network to a fair or better condition.

The PEMS calculates the change in each of these GWP sources for various funding scenarios and compares to the baseline Do-Nothing scenario.

- Greater expenditure leads to higher Embedded & Delay GWP but reduced User GWP and reduced Backlog.
- Conversely, lower expenditure leads to reduced Embedded & Delay GWP but increased User & Backlog GWP.

The PEMS attempts to identify the optimum level of spending to balance condition, cost and GWP over the pavement life cycle.

PEMS Inputs

Treatment Catalog: Each treatment type is characterised by both its financial and GWP cost. Treatment triggers and resets are fully configured. Expected daily productivity (used for delay cost calculations) is also included.

SubNetwork	Treatment	Surface (mm)	Binder (mm)	Base (mm)	GWP Cost (kg/m2)	€ Cost
0 - Motorway	Overlay	40	60	0	28.52	100
0 - Motorway	Reconstruction	40	60	150	94.75	190
0 - Motorway	Replace Surface	50	0	0	14.71	45
0 - Motorway	Strengthen	40	60	75	51.63	130
1 - Other Engineered Pavement	Overlay	40	60	0	28.52	95
1 - Other Engineered Pavement	Reconstruction	40	60	150	94.75	175
1 - Other Engineered Pavement	Replace Surface	50	0	0	14.71	30
1 - Other Engineered Pavement	Strengthen	40	60	75	49.71	125
2 - Urban Areas	Overlay	40	60	0	28.52	95
2 - Urban Areas	Reconstruction	40	60	150	88.99	170
2 - Urban Areas	Replace Surface	50	0	0	14.71	25
2 - Urban Areas	Strengthen	40	60	75	47.79	120
3 - Legacy Pavements High Traffic	Overlay	40	60	0	28.52	85
3 - Legacy Pavements High Traffic	Reconstruction	40	60	100	83.23	135
3 - Legacy Pavements High Traffic	Replace Surface	50	0	0	14.71	25
3 - Legacy Pavements High Traffic	Strengthen	40	60	75	45.87	95
4 - Legacy Pavements Low Traffic	Overlay	40	60	0	28.52	65
4 - Legacy Pavements Low Traffic	Reconstruction	40	60	100	73.63	125
4 - Legacy Pavements Low Traffic	Replace Surface	50	0	0	14.71	25
4 - Legacy Pavements Low Traffic	Strengthen	40	60	75	40.11	80

PEMS Inputs

Fleet make-up: The current make up of the fleet in terms of fuel type is input. The expected change in fleet make-up, particularly EV uptake rates, is modelled over the analysis period.

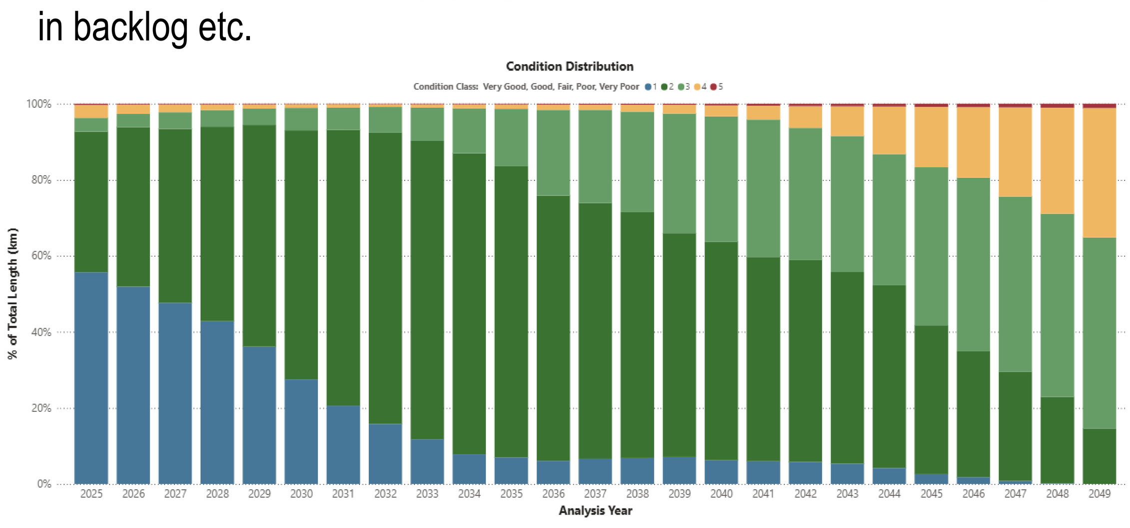
			Fuel Type Distribution			EV Take Up Rate Years:			
	Vehicle Class	Volume Distribution	BEV	Petrol	Diesel	1 to 5	6 to 10	11 to 15	16 to 20
CV	Large Goods Vehicle	53%	25%	0%	75%	0.25%	0.25%	0.25%	0.25%
CV	Other Goods Vehicle	20%	15%	0%	85%	0.25%	0.25%	0.25%	0.25%
CV	Other Goods Vehicle 2	20%	10%	0%	90%	0.25%	0.25%	0.25%	0.25%
CV	Public Service Vehicle	7%	20%	0%	80%	0.25%	0.25%	0.25%	0.25%
PV	Passenger Vehicle	100%	30%	35%	35%	1.00%	1.00%	1.00%	1.00%

Fuel Consumption: Fuel consumption rates for each vehicle type is modelled. Fuel Consumption rates are adjusted based on predicted IRI (NCHRP 720)

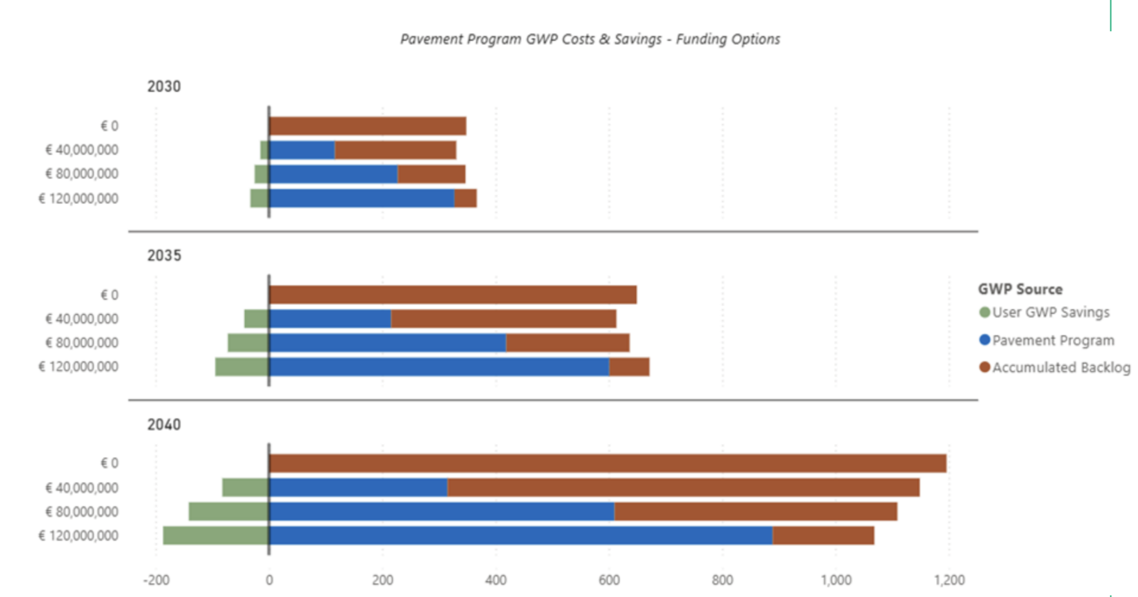
Fuel Consumption Function	$L = a/v + b + c*v + d*v^2$ Where: L = consumption (litre/km) v = average speed (km/hr) a, b, c, and d = fuel consumption parameters			
	a	b	c	d
Petrol Car	0.5155	0.06767	-0.0007362	0.000005619
Diesel Car	0.4229	0.06613	-0.0006266	0.000004798
Electric Car		0.221		
Petrol LGV	0.2535	0.2081	-0.0033072	0.0000212
Diesel LGV	0.218	0.13917	-0.0023135	0.000018692
Electric LGV		0.259		
OGV1	2.5876	0.11176	-0.0006445	0.000009922
OGV2	5.0715	0.34664	-0.0027069	0.000014479

PEMS Outputs

Standard PMS outputs e.g. program cost, condition distribution, length in backlog etc.



Environmental metrics e.g. Programme GWP, Total GWP, Don-Nothing comparisons etc



Conclusions

The TII PEMS accounts for four principal components of lifecycle carbon: (i) user emissions influenced by pavement condition; (ii) embodied carbon from maintenance activities; (iii) additional emissions from traffic delays and detours; and (iv) backlog GWP associated with deferred interventions.

Improvements in pavement smoothness can yield long-term reductions in user GWP. Short-term reductions in GWP achieved by delaying treatments provide an early life reduction in GWP however it may lead to greater lifecycle emissions due to deterioration and more intensive interventions later.

The PEMS demonstrates a practical method of embedding lifecycle carbon assessment into pavement management. By treating carbon as a core optimisation criterion, it offers a structured, transparent approach that can inform sustainable investment decisions in national roads and provide a model applicable to other infrastructure domains

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